PATENT SPECIFICATION (11) 1 342 930

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(21) Application No. 16281/71 (22) Filed 21 May 1971
(23) Complete Specification filed 22 May 1972
(44) Complete Specification published 9 Jan. 1974
(51) International Classification H02M 1/08
H02P 7/42 // 7/58
(52) Index at acceptance
H2F 9J8 9K11 9K12 9N1B2 9N2A 9N4B 9P1 9R27C
9RXC 9T2
H2J 12N3Y 12NX 1B 1D2 1J 1U
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(54) IMPROVEMENTS RELATING TO PULSE WIDTH MODULATION SYSTEMS

(71) We, THE ELECTRICAL RESEARCH ASSOCIATION, a British Company of, Cleeve Road, Leatherhead, Surrey, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

A known techinque for synthesising low frequency generally sinusoidal waveforms is by feeding a pulse width modulated waveform to an integrating filter, the width of the pulses being related to the amplitude of the desired waveform at any instant.

A common method of obtaining the necessary pulse width modulated waveform is to compare a reference sine wave with a high frequency carrier having a triangular or sawtoothed waveform. The resulting difference signal can then be amplified and converted into a logic signal. The method requires complex linear and digital circuits particularly for three phase systems requiring a three phase reference with both phase balance and amplitude control over wide frequency and amplitude ranges. An example of such a system is a variable frequency three phase motor drive.

In accordance with the present invention a method of generating a pulse width modulated waveform which may be integrated to form a generally sinusoidal waveform comprises feeding two squarewaves to respective inputs of either an exclusive-OR or an equivalence gate, the squarewaves having a difference in frequency equal to the required frequency of the waveform to be synthesised.

An important advantage of this system is that it is possible to vary the frequency of the final sinusoidal waveform over a wide range merely by varying the frequency of one of the squarewaves.

In a preferred embodiment of the invention the logic gate output signal is used to control the switching of a static bridge inverter to produce a positive output for one logic state and a negative or zero output for the other logic state. The output from the inverter may then be used to drive a motor, the inductance in the motor windings providing the necessary integration of the pulse width modulated waveform to derive the required sinusoidal output.

The invention is particularly useful for very low frequency systems (approaching D.C.) where a wide frequency range is required, but can also be used to generate frequencies of up to 1 Mc/S provided that the higher of the two squarewave frequencies is very much higher than the final output frequency. In other words the two squarewave frequencies should always be close enough together to develop a strong 'beat' frequency which will be the required output frequency.

Three phase operation can be achieved simply by further combining a first of the squarewaves with third and fourth squarewaves at respective exclusive-OR or equivalences gates, the third and fourth squarewaves having the same frequency but differing in phase from one another. A particular advantage of such a system is that the phase rotation is controlled simply by which of the two frequencies is the higher so that the phase rotation can easily be reversed by interchanging the two frequencies. This is particularly useful on motor drive systems since reversing is often required.

Amplitude control can be achieved by generating a third squarewave of the same frequency as a first of the squarewaves but of different phase and combining the third squarewave with the second squarewave at a second exclusive-OR or equivalence gate. The outputs of the two logic gates are then summed to obtain a resultant signal having an amplitude proportional to the difference

in phase between the first and third squarewaves but retaining the same modulation frequency.

In order that the invention may be more clearly understood one example will now be described with reference to the accompanying drawings in which:—

Figure 1 is a block diagram of a variable frequency three phase motor drive system;

Figures 2*a-c* are waveform diagrams of the voltages at various points in the block diagram of Figure 1 when generating high, medium and low voltages respectively, and

Figures 3*a-b* are waveform diagrams illustrating three phase operation with normal and reverse phase rotation.

In Figure 1 a main squarewave oscillator M1 feeds signals to a pair of bistable divider circuits B1, B2 which divide the frequency by different amounts to provide two signals differing in frequency by an amount equal to the desired output frequency of the motor. The signal from the bistable B1 is fed to a ring counter and the 120° outputs of the ring counter are combined with the output from the bistable B2 at exclusive-OR gates G1, G2, G3. Each phase output consists of a pulse width modulated waveform in which the modulating frequency equals the difference frequency between the outputs of B1 and B2. The phase outputs are fed to respective first arms of a three phase static bridge inverter I1 to control the switching elements S1-S6.

At the same time the 120° outputs of the ring counter are fed to a second set of exclusive-OR gates G4, G5, G6 together with an output from a bistable B3 which produces the same output frequency as the bistable B2 but delayed in phase. The outputs from the gates G4, G5, G6 are used to control the switching elements S7-S12 in the respective second arms of the bridge inverter I1. The motor windings L1, L2, L3 are connected across the junction of the respective arms of the bridge so that the motor is driven at the modulation frequency. The switching of static inverters using pulse width modulation is well known and will not therefore be described in detail.

Figure 2*a* illustrates one of the squarewaves f_{A0} which is fed to the exclusive-OR gate G1 from the ring counter, and the square wave f_{B0} which is fed to the second input of the gate G1 from the bistable B2. The resulting output waveform f_{C0} is pulse width modulated at the desired output frequency. The waveform f1 illustrates the voltage at the junction A between the switching elements S1, S2, and the waveform f1 is summed with a similar waveform f2 which appears at the junction B in the opposite arm of the inverter between the switching elements S7, S8. The effective voltage across the coil L3 of the motor is therefore the sum of S1 and S2 which is shown as the waveform F3. The waveform f2 is obtained by combining the waveform f_{B1} obtained from the bistable B3 with the waveform f_{A0} obtained from the ring counter at an exclusive-OR gate G4 to obtain the resultant pulse width modulated waveform f_{D0}.

The waveforms illustrated in Figures 2*b* and 2*c* correspond to those shown in Figure 2*a* but illustrate the generation of medium and low amplitudes respectively by varying the phase of f_{B1}.

The waveforms illustrated in Figure 3*a* illustrate the three phase outputs f_{A0}, f_{A1}, f_{A2} from the ring counter and the resulting outputs f_{C0}, f_{C1}, f_{C2} from the gates G1, G2 G3 respectively. Those of Figure 3*b* correspond to 3*a* but illustrate the reversal of phase rotation achieved when the frequency f_B is made greater than f_A.

WHAT WE CLAIM IS:—

1. A method of generating a pulse width modulated waveform which may be integrated to form a generally sinusoidal waveform, comprising feeding two squarewaves to respective inputs of either an exclusive-OR or an equivalence gate, the squarewaves having a difference in frequency equal to the required frequency of the waveform to be synthesised.

2. A method according to claim 1 in which a first of the squarewaves is further combined with third and fourth squarewaves at respective exclusive-OR or equivalence gates, the third and fourth squarewaves having the same frequency as the second squarewave but differing in phase from one another whereby the three logic gates produce a three phase output.

3. A method according to claim 1 in which a third squarewave of the same frequency as a first of the squarewaves but of different phase is combined with the second squarewave at a second exclusive-OR or equivalence gate, and in which the two logic gate output signals are summed to obtain a resultant pulse width modulated signal having an amplitude proportional to the difference in phase between the first and third squarewaves.

4. A waveform synthesiser including: means for generating a pair of squarewaves of different frequency, either an exclusive-OR gate or an equivalence gate connected to receive the two squarewaves at respective inputs, and an integrator responsive to the logic gate output to produce a generally sinusoidal waveform having a frequency equal to the difference in frequency between the two squarewaves.

5. A waveform synthesiser according to claim 4 further including a static bridge inverter connected between the logic gate

and the integrator and having switching elements responsive to the output signal of the logic gate such that the inverter output is switched between two voltage levels to produce a corresponding pulse width modulation waveform of increased amplitude.

6. A variable frequency three phase motor drive system including a waveform synthesiser according to claim 5 and further including means for generating third and fourth squarewaves having the same frequency as the second squarewaves but differing in phase from one another, and two further exclusive-OR or equivalence gates for combining the first squarewave with the third and fourth squarewaves respectively to produce a three phase pulse width modulated output from the three logic gates; the static inverter including three pairs of switching elements responsive to respective outputs from the three logic gates, and each inverter output being fed to a winding of the motor being driven.

7. A method according to claim 1 substantially as herein described with reference to the accompanying drawings.

8. A waveform synthesiser according to claim 4 substantially as herein described with reference to the accompanying drawings.

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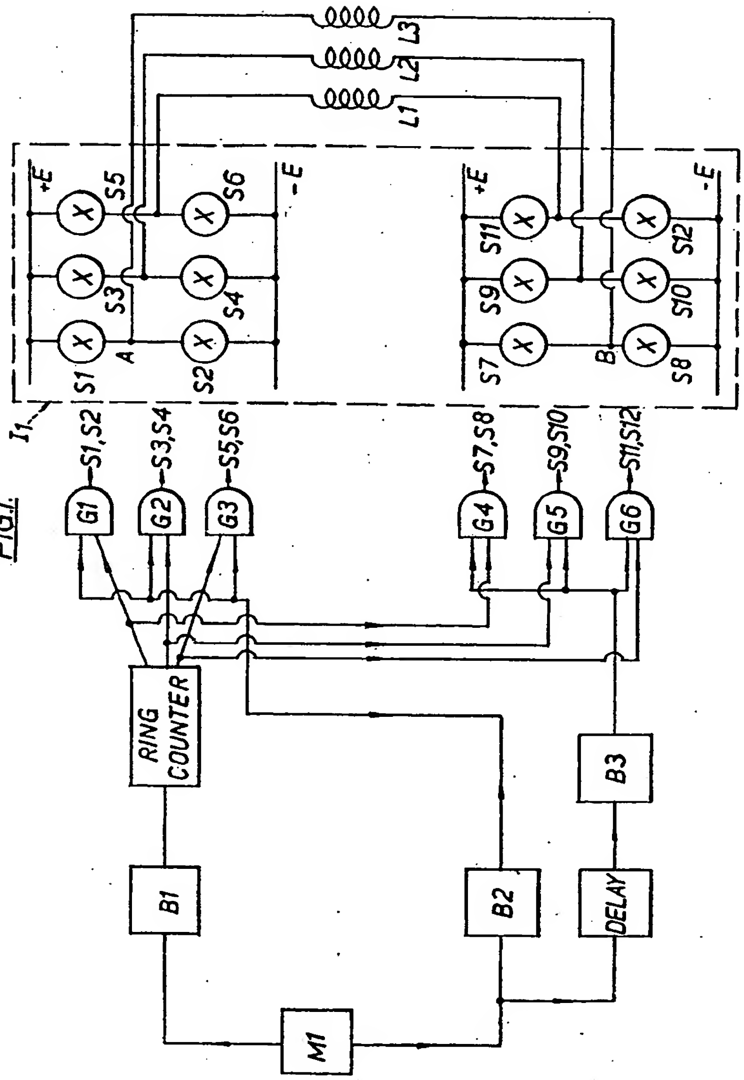
Printed for Her Majesty's Stationery Office by The Tweeddale Press Ltd., Berwick-upon-Tweed, 1973.
Published at the Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.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L2
L3
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S1
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S9
S10
S11
S12
A
B
I1
S1,S2
S3,S4
S5,S6
S7,S8
S9,S10
S11,S12
G1
G2
G3
G4
G5
G6
RING COUNTER
B1
B2
B3
DELAY
M1

FIG.1

FIG.2a.

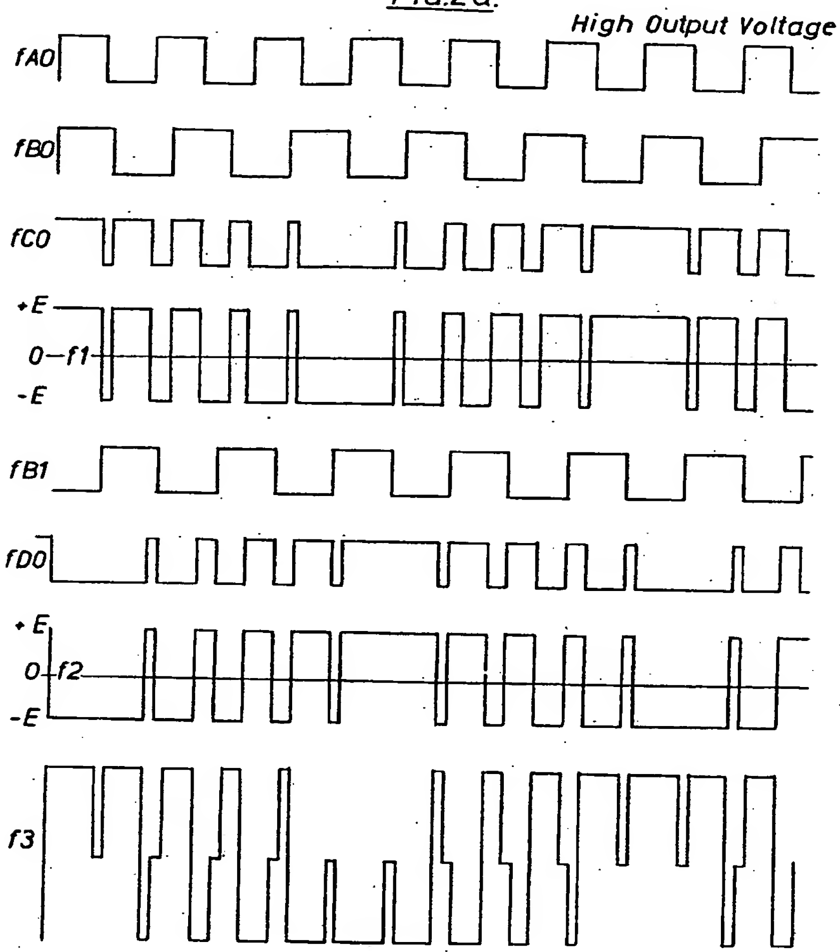


FIG. 2 b.

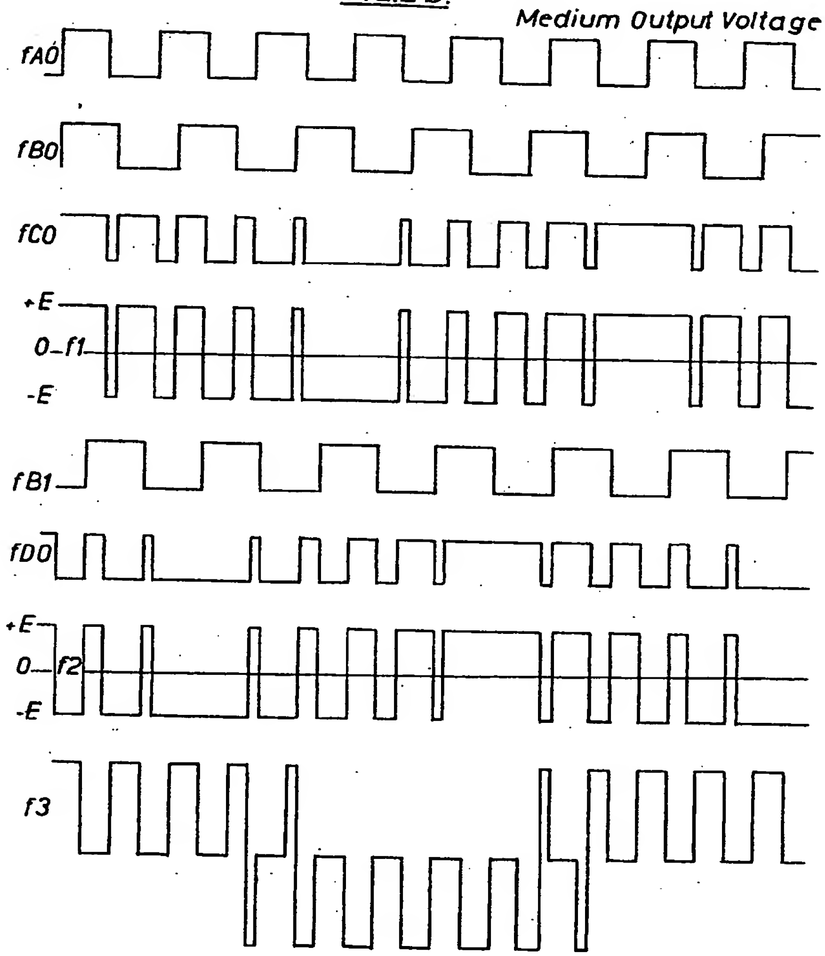


FIG. 2c.

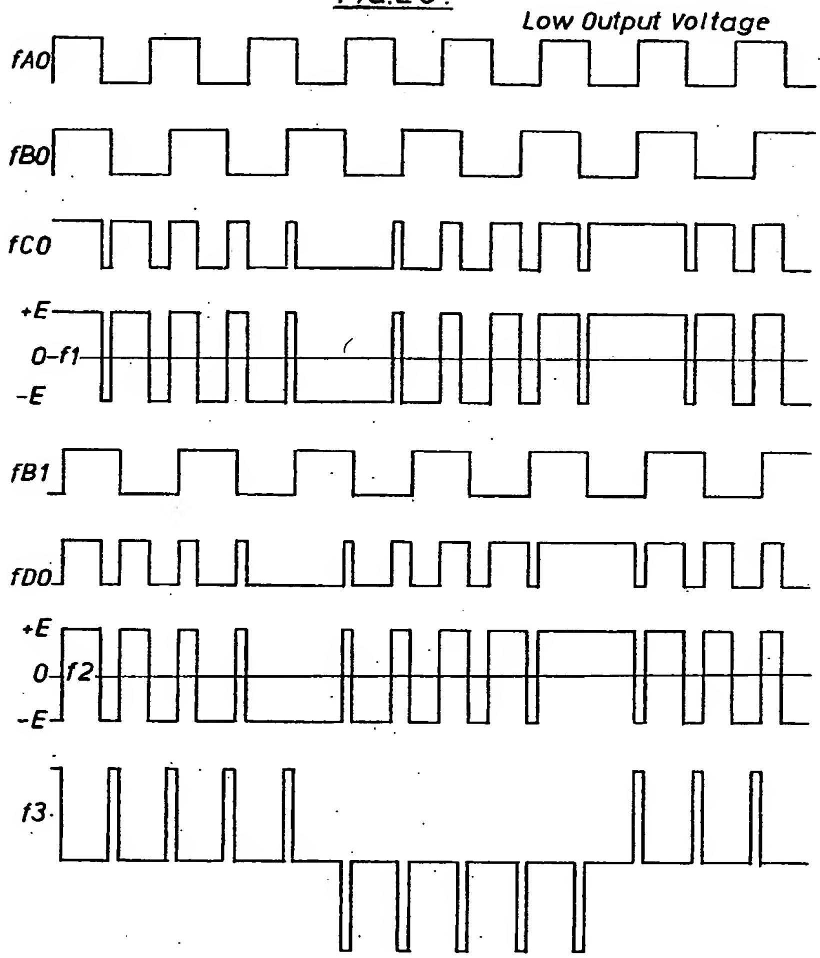
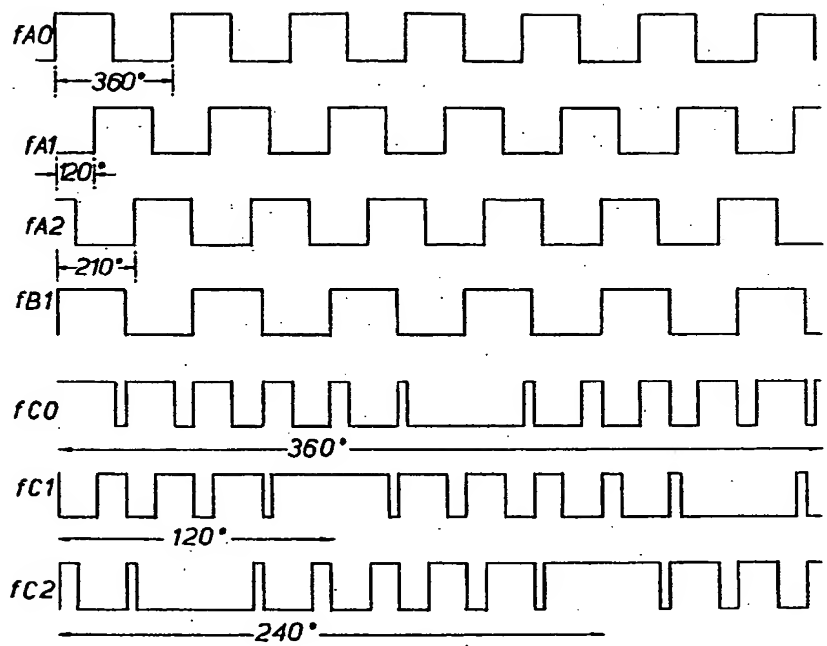
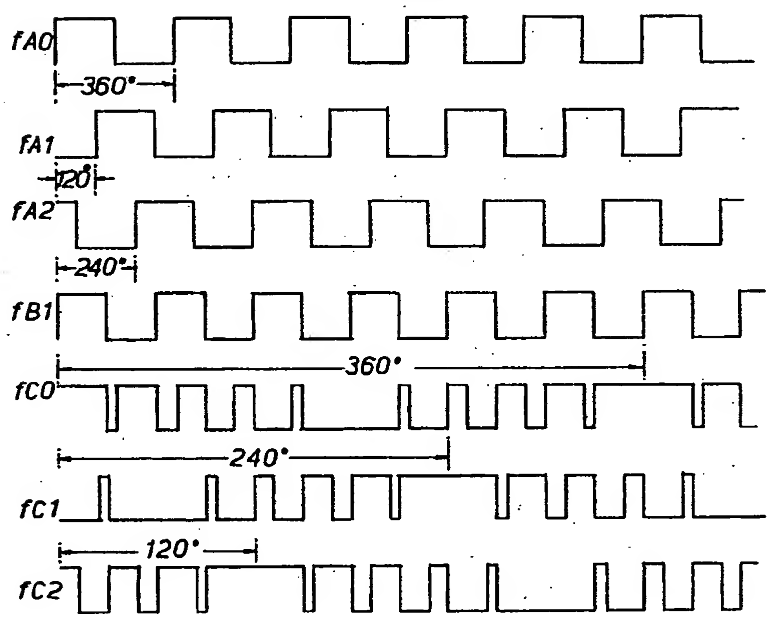


FIG. 3a.



Normal Phase Rotation

FIG. 3 b.



Reverse Phase Rotation